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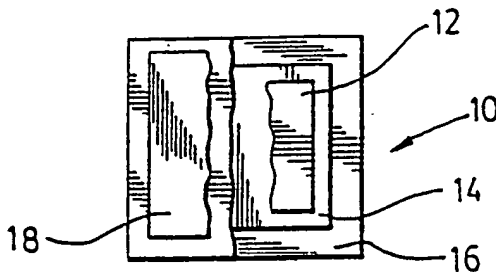
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(54) Title: RADIATION REDUCTION FILTER FOR USE IN MEDICAL DIAGNOSIS

**(57) Abstract**

In accordance with the present invention, there is provided an X-ray filter which significantly reduces low energy radiation normally absorbed by the examination object without significantly affecting the desired high energy radiation. The filter is comprised of one or more materials (12) containing as the major component elements selected from the group consisting of aluminum and elements having atomic number between 26 and 50 with the filter being selected to have X-ray filtering characteristics such that the intensity of X-rays having energies of 50 keV are reduced by about 8 % to about 35 % of the normal radiation levels. As a result of the construction immediately above, the filter of the present invention filters energy from the X-ray beam which is usually absorbed by the examination object and does not contribute to the radiographic image of the examination object. This is achieved with little, if any, increased loading of the X-ray tube which would other-

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RADIATION REDUCTION FILTER FOR USE IN MEDICAL DIAGNOSIS

FIELD OF THE INVENTION

5 This invention relates to X-ray radiography and fluoroscopy and particularly to filters for limiting the radiation dosage to a patient exposed to X-rays during medical and dental diagnosis.

10 BACKGROUND OF THE INVENTION

 X-rays are produced in an X-ray tube as a result of high speed electrons striking a target material. The electrons strike and penetrate the
15 surface layers of the target material and through interaction or collision with the atoms of the target, the energy of the electron is imparted to the electrons in the target.

20 If, in striking the target, the energy of the electron is dissipated through a series of collisions with the outer electrons of the target atoms, then the energy is released either in the form of heat or as visible light. An electron may, after a series of
25 collisions, also emerge from the target as a back-scattered electron. These collisions result in most of the energy losses contributing to target heating and hence reduced X-ray tube life.

30 The electron may also have radiative collisions, giving up part or sometimes all of its energy to photons. The photons produced as a result of these collisions have an energy less than or equal to the energy given up by the electron.

35 If the energy of the electron is sufficient to collide with and eject an electron from the inner K-shell of the target atom, then the excited target atom,

when the electrons in the outer shells drop into the vacant inner shell, will return to its ground state and a photon will be emitted. The energies of these transitions are dependent upon the atoms comprising the target material and hence the energies of the photons emitted are characteristic of the target atom. This radiation is known in the art as the characteristic X-ray radiation and is produced by the X-ray tube only when the energy of the electron striking the target is above the level required to dislodge the K-electron of the target atom.

The energy of the photon comprising the X-ray is directly related to the energy given up by the electron in the collision with the target molecules. As it is well known that the relationship between the wavelength (λ) of a photon and its energy is expressed by the Duane-Hunt equation:

$$\lambda = \frac{12.4}{\text{keV}} \text{ \AA}$$

this process results in X-rays of various wavelengths which constitute what is known in the art as the continuous X-ray spectrum.

The ability of the X-rays to penetrate an examination object depends on the wavelength or energy of the X-ray photons as well as the composition of the examination object - i.e. its chemical elements, thickness and density. With respect to the wavelength or energy of the X-rays, generally the penetration ability is inversely proportional to wavelength or directly proportional to energy. Thus, short wavelength (high energy) X-rays have a greater penetrating ability than long wavelength (low energy) X-rays. With respect to the chemical elements making up the examination object, generally, the higher the atomic number of the element, the less the penetration of the X-ray beam.

However, at wavelengths or energy levels near the absorption edges of the elements, these generalizations do not hold true as there are discontinuities in the degree of absorption of the X-ray beam at these points.

5 With respect to the thickness and density of an examination object, generally, the thicker and denser the object the greater its ability to absorb X-rays and thus fewer X-rays pass through the object. It is the combination of these factors as they relate to different
10 compositions of material which allows for the differential diagnosis of radiography. Thus, the selection of the operating parameters of the X-ray apparatus during medical diagnosis depends upon the examination object, its chemical composition, thickness
15 and density. For more descriptions of the above, reference can be made to textbooks of medical physics or radiology.

As low energy X-rays do not normally contribute
20 to the resolution of the method but are merely absorbed and scattered by the examination object, it is highly desirable to remove such X-rays from the X-ray beam prior to the beam contacting the examination object. These low energy X-rays are usually removed from the X-
25 ray beam through the use of attenuators or filters.

Similar to the effects on examination objects, the attenuating ability of a filter is dependent upon the chemical composition, density and thickness of the
30 material making up the filter. These relationships are represented by the following equation:

$$I = I_0 e^{-\mu \rho x}$$

35 where I is the intensity of the radiation transmitted, I_0 is the intensity of the incident radiation, e is the base of natural logarithm, μ is the mass attenuation coefficient for the chemical element comprising the filter

material, ρ is the density of the filter material, and x is the thickness of the filter material.

Of the above factors, all except the
5 attenuation co-efficient μ are independent of the frequency or energy of the incident radiation. The attenuation co-efficient varies with the energy of the incident radiation and is related to the atomic number of the chemical element of the filter material. These
10 co-efficients have been experimentally determined and can be found in published tables, such as, for example, in UCRL 50174 by W.H. McMaster et al available from the National Technical Information Services, Springfield, Va., 22151.

15 For many years the most common means of filtration of X-rays used in medical and dental diagnosis has been through the use of aluminum filters. As an example, U.S. Patent 2,225,940 discloses a wedge
20 which is brought into the path of the X-ray beam. Additionally, U.S. Patent 3,976,889 discloses the use of variable thicknesses of aluminum filters in dental x-rays to vary exposure levels. Almost all commercial x-ray units have some inherent filtration equivalent to
25 about 1.0 to 1.5 mm of aluminum and those designed for medical and/or dental applications, utilize additional aluminum filtration.

The use of filters other than aluminum to
30 filter low energy X-rays from an X-ray beam was the subject of U.S. Patent 4,499,591, wherein a 127 micron thick yttrium filter was employed to filter the X-ray beam such that energies below 20 keV were eliminated from the beam. Also Heinrick and Schuster, "Reduction
35 of Patient Dose by Filtration in Pediatric Fluoroscopy and Fluorography" Ann. Radiol. (1976) Vol.19. pages 57-66, utilized a molybdenum filter of 100 microns to remove radiation below 20 keV from the X-ray beam.

Koedooder and Venema; Phys. Med. Biol. (1986)

Vol , pages 585-600 describe a computer program which was developed to calculate possible filter materials for use with a range of kVP values and different image receptors. In their results they found that dose reductions of up to 40% were achievable, however, in most cases the loading of the X-ray tube was doubled resulting in reduced life of the X-ray tube.

In X-ray crystallography and diffraction studies, it is useful to have relatively homogeneous, monochromatic X-ray beams. Filter materials have been used for producing these relatively homogeneous X-ray beams by limiting the range of wavelengths of the X-ray beam. Thus, in U.S. Patent 1,624,443, the use of a filter with a slightly lower atomic weight than the X-ray tube target has been found to produce an X-ray beam of suitable relative homogeneity for use in X-ray crystallography. This patent discloses, in a preferred embodiment, the use of a zirconium filter with a molybdenum target. The use of filters of the same material as the target has also been shown to result in an X-ray beam of relative homogeneity. U.S. Patent 3,515,874 discloses the use of molybdenum for both a target and filter, particularly for mammography where it has been found that the energy level of the K α line emitted from a molybdenum target is ideal for resolution of tumors in mammography applications.

As seen from the above, it is appreciated that there is a risk involved when dealing with diagnostic X-rays due to the harmful effects of unnecessary radiation dosages. Therefore, there is a need for an efficient X-ray filter to reduce such dosages and which is compatible with existing X-ray equipment.

SUMMARY OF THE INVENTION

In accordance with the present invention, there is provided an X-ray filter which significantly reduces low energy radiation normally absorbed by the examination object without significantly affecting the desired high energy radiation. The filter is comprised of one or more materials containing as the major component elements selected from the group consisting of aluminum and elements having atomic numbers between 26 and 50 with the filter being selected to have X-ray filtering characteristics such that the intensity of X-rays having energies of 50 keV are reduced by about 8% to about 35% of the normal radiation levels.

In an aspect of the invention, the filter is encased in a thin plastic sheet which provides for protection of the filter during handling as well as some absorption of the secondary radiation emitted from the filter when it is contacted by the X-ray beam.

In another aspect of the invention, the filter is comprised of a metal foil constructed of a single elemental material, the elemental material being selected from the group consisting of niobium, copper, silver, tin, iron, nickel, zinc, zirconium, aluminum or molybdenum.

In yet another aspect of the invention, the filter is comprised of a niobium metal foil having a maximum thickness of about 75 microns or a niobium metal foil in combination with additional filtering foils.

As a result of the construction immediately above, the filter of the present invention filters energy from the X-ray beam which is usually absorbed by the examination object and does not contribute to the radiographic image of the examination object. This is

achieved with little, if any, increased loading of the X-ray tube which would otherwise reduce its effective life. These and other features of the present invention will be appreciated from the detailed description of the preferred embodiments of the invention which follow.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention are shown in the accompanying drawings in which,

Figure 1 shows a perspective view of a filter constructed in accordance with the present invention;

Figure 2 is a sectional view of the filter of figure 1;

Figure 3 is an elevational view of an X-ray diagnostic apparatus with the filter of the present invention in place;

Figure 4 is an x-ray wavelength spectrum of the typical apparatus of figure 3, showing both filtered and unfiltered spectrum; and

Figure 5 is an X-ray wavelength spectrum of the apparatus of figure 3, showing the unfiltered and the filtered spectrum wherein a filter of a second embodiment of the present invention has been utilized.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

Figures 1 and 2 show a preferred embodiment of a filter of the present invention generally indicated at 10 comprising a metal foil 12 preferably constructed of an elemental material selected from the group consisting of niobium, copper, silver, tin, iron, nickel, zinc, zirconium or molybdenum. A particularly suitable construction is niobium in a thickness of up to about 75 microns, preferably about 40 to 60 microns, the most preferable thickness of the niobium metal foil being

about 50 microns. This metal foil is encased in a coloured cardboard 14 wherein the colour can be used as an identifying means for the filter material and its thickness or the application in which the filter is to be utilized. Overlying and encasing the filter 12 and cardboard envelope 14 is a plastic covering 16 which serves as a protective covering to the filter.

Additionally the combination of the cardboard 14 and the plastic covering 16 serves to absorb some of the

secondary radiation emitted from the metal foil 12 when an X-ray beam contacts the metal foil and also reduces or eliminates the exposure of the metal foil to air, thereby reducing oxidation. Attached to one side of the filter 10 is a means for attaching the filter to the X-ray unit shown in the figures as a strip of double sided tape 18. The method of attaching the filter to an X-ray apparatus is discussed below.

Figure 2 shows a cross-section of the filter 10 of figure 1 illustrating clearly the relationship between the metal foil 12, the cardboard envelope 14 and the plastic encasing material 16.

Figure 3 illustrates an X-ray generating apparatus 20 of typical lead based construction. The apparatus comprises an X-ray tube 30 with a cathode 22 and a rotating anode 24. Located within the cathode is a filament (not shown) which when heated by an electric current produces a cloud of electrons around the cathode. When high voltage from a generator (also not shown) is applied across the cathode 22 and the anode 24, the electrons in the cloud surrounding the cathode are accelerated as a beam towards the anode 24 which is comprised of a metallic material suitable as a target. Most commonly, the target is constructed of tungsten. When the electron beam strikes the target material, the energy of the electron beam is absorbed by the target

material and results in the production of X-rays as explained hereinabove.

Owing to the construction of the anode 24, the X-ray beam is, to a large degree, focused and emitted from the X-ray apparatus 20 through a port 26. Port 26 usually comprises a window made of glass or plastic with an inherent filtration equivalent to about 0.5 mm of aluminum. In the typical applications, the X-ray beam emitted from the tube is focused through the use of a collimator 28. The purpose of collimator 28 is to direct the X-ray beam to cover only the area required in exposure of the examination object. This is achieved through adjustment of diaphragms 32 and 36, setting the collimator opening 34.

The X-ray apparatus also has inherent and added filtration (not shown), usually equivalent to 2.5 to 3.5 mm aluminum to remove, from the beam, very low energy X-rays which would be generally absorbed within the first few millimetres of the examination object. These very low energy X-rays do not contribute at all to the resolution of the radiograph, but rather merely contribute to increase the exposure dose of the examination object 42. The X-ray beams, once they pass through the examination object 42, are detected by a radiation detecting device as for example, an image intensifier 38 or directly on a radiographic film 40.

Filter 10 is shown attached in the apparatus between the port 26 of the tube 30 and the collimator 28. The filter is attached to the apparatus using the double sided tape 18, by sticking it onto either the port 26 of the tube 30 or the additional aluminum filtration. Alternatively, in those applications where this may not be possible, i.e. in some dental applications, it may be fixed in the opening of the collimator.

Figure 4 shows generally the X-ray wavelength spectrum emitted from an X-ray apparatus of figure 3. The apparatus with a tungsten target and 3.5 mm of aluminum equivalent filtration was operated at an accelerating voltage of 80 kVP thereby resulting in production of a continuous spectrum with a minimum wavelength of about 0.15 \AA and the characteristic $K\alpha$ and $K\beta$ radiations of tungsten of about 0.21 \AA and 0.18 \AA respectively. The solid line shows the wavelength spectrum of the the normal radiation X-ray beam emitted from the apparatus prior to filtration by a 50 micron niobium filter. The long dash line is the attenuation properties of the 50 micron niobium filter. Niobium with an atomic number of 41 has a K absorption edge at about 0.65 \AA and an L_I absorption edge at about 4.58 \AA (not shown on the figure). The short dash line shows the wavelength spectrum of X-ray beam after passing through the niobium filter. There is a marked decrease in the X-ray wavelengths from about 0.25 \AA to just before the K absorption edge at 0.65 \AA wherein only about 3% of the incident normal radiation is not absorbed by the filter. Thereafter the normal radiation of the X-ray beam is attenuated such that effectively all of the radiation is absorbed.

The choice of filter materials for the filters is dependent upon the requirements of the diagnostic technique as different techniques may require differing X-ray wavelength spectrums. For most medical and dental diagnostic techniques wherein the X-ray apparatus is operated at a peak voltage of between 55 keV and 110 keV, then any material whose major component is an element having an atomic number between 26 and 50 will be suitable for attenuating the X-rays beam. The elements having atomic numbers between 26 and 50 have K absorption edges between about 7 keV and 30 keV and

hence in these kVP ranges will not exhibit appreciable K-edge phenomenon and hence will generally act as non-specific filters. The choice of the filter materials is also dependent upon availability of the material in a form suitable for filter construction, preferably in a metal foil of a suitable thickness.

Owing to the characteristics of these materials, particularly for those elements available as metal foils, relatively thin filters are required, varying between generally on the order of 200 microns and less, the preferred materials resulting in X-ray filters having thicknesses on the order of 30 to 120 microns, the most preferred materials resulting in X-ray filters having thicknesses on the order of 30 to 70 microns. This is illustrated in the following table which lists the preferred metal foil filter materials and the preferred thickness.

	At.No	Element	Thick Range	Thick Preferred
10	26	Fe	50-250	125
	27	Co	50-225	125
	28	Ni	50-200	100
	29	Cu	50-180	120
	30	Zn	60-205	125
15	38	Sr	100-305	205
	39	Y	55-165	100
	40	Zr	35-105	70
	41	Nb	25-75	50
	42	Mo	20-60	40
20	43	Tc	15-50	35
	44	Ru	15-45	30
	46	Pd	15-40	30
	47	Ag	15-45	30
	48	Cd	20-50	35
25	49	In	20-60	40
	50	Sn	20-55	35

Those elements having atomic numbers between 26 and 50 which are not available as metal foils may be
5 utilized by alloying them with one of the other materials. Particularly useful for alloying purposes is aluminum. Filters constructed in accordance with the present invention are easily adaptable to existing X-ray
10 installations, thus resulting in reduced radiation exposure to the patient without significant increased cost. The filters also have the added benefit of reducing incident scattered radiation from the X-ray source, thereby reducing the levels of radiation to which operators of such equipment may be exposed.

15 If it is desirable to remove from the X-ray beam, all radiation having energy near the K absorption edge of niobium without appreciably increasing the attenuation of the beam in the diagnostically important
20 region (generally from about 0.15 A° to about 0.4 A°), then a combination filter can be utilized. The combination filter will contain one or more materials containing more than one element selected from the group consisting of aluminum and elements having atomic
25 numbers between 26 and 50. The combination filter can be constructed by layering individual metal foils or by alloying the materials into a single foil. The selection of the materials and the elements comprising the materials will be dependent upon the desired
30 spectrum of the X-ray beam which in turn will be dependent upon the particular application.

As shown in figure 5 a combination filter of 25
microns of niobium and 50 microns of selenium is
35 utilized. The keys to the curves are the same as in figure 4 where the solid line is the unfiltered spectrum, the long dash line is the attenuation profile of the combination filter and the short dash line is the

filtered spectrum. As is clearly shown, by employing selenium with a K absorption edge of about 0.98 \AA , in combination with niobium, substantially all of the X-rays with wavelengths greater than about 0.6 \AA are removed from the X-ray beam by the combination filter.

Thus, in the example shown in figure 5, the combination of niobium and selenium is particularly useful for applications where it is desirable to have an X-ray beam with wavelengths less than about 0.4 \AA . If a harder beam is desired, i.e. one where the wavelengths are less than 0.3 \AA or 0.2 \AA , then the filter material would be chosen to remove X-rays with wavelengths longer than this. For example, tin with a K absorption edge at about 0.42 \AA or indium with a K absorption edge at about 0.44 \AA or silver with K absorption edge at about 0.48 \AA would be useful. The above or other materials similar in attenuation properties would be used in combination with one or more materials having K absorption edges in the region of about 0.6 \AA to 1.0 \AA as for example materials from technetium to germanium in the periodic table.

The preferred thickness of the selected materials is dependent upon the density and attenuation co-efficients as discussed above. Generally the total thickness of the filter should be chosen such that the product obtained by multiplying together the thickness, the density and the attenuation coefficient at 50 keV is in the range of about 0.15 to about 0.45, most preferably from about 0.25 to 0.35. In a combination filter the sum of the products for each of the individual elements should be in the above ranges. Preferably for a combination filter comprising two separate elements, each of the individual elements should be in the range of about 0.075 to about 0.225 and most preferably from about 0.125 to about 0.175.

The use of a filter of the present invention will be illustrated further in the following examples:

5

EXAMPLE I

10 A 50 micron niobium filter encased in plastic was placed at the face of the collimator of a 3 phase 6 pulse unit with a total filtration of 3.5 mm. aluminum equivalent. Entrance doses were measured using a Victoreen exposure meter. A series of radiographs were taken of phantoms with and without the niobium filter. In order to achieve identical optical density in the
15 radiographs the exposure for the filtered radiographs was increased slightly by 8 to 10%. The dose reduction values have been corrected for the slight increase in exposure.

20

TABLE I - MEASURED ENTRANCE DOSE

kV RANGE (kVP)	WITHOUT TEST	WITH TEST	% DOSE
	FILTER	FILTER REDUCTION	
25 40	.9mr/mas	.22mr/mas	75%
50	2.0	.55	72
60	3.4	1.21	64
70	5.0	2.1	58
30 80	6.7	3.1	54

TABLE I shows a significant reduction in entrance dose between measurements taken with and without the niobium filter. This dose reduction is most
35 marked for the lower kVP.

EXAMPLE II

This experiment was carried out using a General Electric Three Phase Generator and an automatic beam limiting device with an inherent filtration of 1.5 mm equivalent of aluminum at 150 kVP. The radiation detection device used was a Rad Check Plus, Model No. 06-526. The added filtration was 2.0 mm of aluminum, making a total filtration of 3.5 mm of aluminum equivalent. Since the majority of X-ray examinations are carried out between 75 to 100 kVP, the generator was used at the following settings; mA - 200; Time - .35 Seconds; kVP - 80.

A half value layer experiment was carried out, as well as a comparison of radiation dose obtained under;

- a) Normal operation - with only the 3.5 mm aluminum/equivalent between source and the detector
- b) exactly as in item a), but with 100 microns of Yttrium added at the source in the field.
- c) Exactly as in item a), but with 50 microns of Niobium added at the source in the field.
- d) Exactly as in item a), but with 25 microns of Niobium added at the source in the field.

OPERATION	ADDITIONAL FILTRATION	mR DOSE	% DOSE REDUCTION (COMPARED TO A)
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5

A) NORMAL OPERATION

0	262
1mm	210
2mm	176
3mm	148
4mm	124
5mm	107

10

HALF VALUE LAYER = 3.7mm Al

B) ADDITION OF 100 MICRONS OF YTTRIUM TO A

15

0	149	44
1mm	128	39
2mm	112	37
3mm	95	36
4mm	83	33

20

HALF VALUE LAYER = 4.85mm Al

C) ADDITION OF 50 MICRONS OF NIOBIUM TO A

25

0	138	48
1mm	118	44
2mm	99	44
3mm	83	44
4mm	72	42
5mm	64	40

HALF VALUE LAYER = 4.35mm Al

30

D) ADDITION OF 25 MICRONS OF NIOBIUM TO A

35

0	175	34
1mm	148	30
2mm	125	29
3mm	107	28
4mm	91	27
5mm	79	26

HALF VALUE LAYER = 4.25mm Al

EXAMPLE III

Tests were conducted utilizing water phantoms of 5 cm, 10 cm, 15 cm, and 20 cm in depth. A step wedge was placed in the water to provide a measurable optical density (O.D). A Siemens Tridoros Optimatic 800 generator was used for testing using the 0.6 focal spot size. Testing was done using a Keithly 35055 digital dosimeter at 115 cm FFD. The HVL measured before testing was 3.8 mm Al at 80 kV. A 50 micron niobium filter added to the 3.8 mm Al outside the collimator window. The results are as follows:

	PHANTOM	ADDITIONAL FILTRATION	EXPOSURE	TUBE VOLTAGE	DOSE	% DOSE REDUCTION
	5 cm		10 mAs	63 kV	28.4 mR	
	5 cm	0.05 mm Nb	10 mAs	63 kV	10.2 mR	64%
20	5 cm	0.05 mm Nb	12 mAs	63 kV	16 mR	44%
	5 cm	4 mm Al	10 mAs	63 kV	10.2 mR	64%
	10 cm		20 mAs	77 kV	94 mR	
	10 cm	0.05 mm Nb	20 mAs	77 kV	50 mR	47%
25	10 cm	0.05 mm Nb	25 mAs	77 kV	73 mR	22%
	10 cm	3 mm Al	20 mAs	77 kV	51 mR	46%
	15 cm		32 mAs	96 kV	283 mR	
	15 cm	0.05 mm Nb	32 mAs	96 kV	170 mR	40%
30	15 cm	0.05 mm Nb	40 mAs	96 kV	215 mR	24%
	15 cm	3 mm Al	50 mAs	96 kV	172 mR	39%
	20 cm		50 mAs	117 kV	715 mR	
	20 cm	0.05 mm Nb	50 mAs	117 kV	453 mR	37%
35	20 cm	0.05 mm Nb	64 mAs	117 kV	569 mR	20%
	20 cm	3 mm Al	50 mAs	117 kV	460 mR	36%

EXAMPLE IV

A series of spine and abdomen radiographs were taken under conditions shown in the following table.

5 Measurement of dose was with a Capintec Dosimeter.

	PROJECTION	FFD	kVP	mA	TIME	UNFILTERED DOSE	FILTERED & DOSE REDUCTION	DOSE
10	CERVICAL SPINE	40	70	100	.1	31	7	78
	LATERAL LUMBAR							
15	SPINE	40	90	300	.2	556	264	54
	FULL SPINE	72	90	300	.2	110	50	55
20	ABDOMEN	72	90	300	.2	110	50	55

25

The films taken with the niobium filter were judged by an experienced radiologist and determined to have greater detail than the unfiltered films.

30

EXAMPLE V

Tests were run using a WEBER Dental x-ray unit at 70 kVP and 10 mA with the 50 micron niobium filter.

35

It was found that to achieve equivalent contrast and film quality with the niobium filter, exposure times were increased 1.5 to 2 times the exposure for the aluminum filter alone. In normal operation with the

aluminum filter, exposure times are generally 0.2 to 0.3 seconds, with the addition of the niobium filter they are 0.3 to 0.5 seconds. Dose reductions are shown in the following table:

5

	FILTER	EXPOSURE TIME	DOSE MR	% DOSE REDUCTION
10	Al	0.2	116	69%
	Nb	0.2	36	
	Al	0.2	116	50.9%
	Nb	0.3	57	
15	Al	0.2	116	37.9%
	Nb	0.4	72	
	Al	0.3	171	66.7%
	Nb	0.3	57	
20	Al	0.3	171	57.9%
	Nb	0.4	72	
	Al	0.3	171	50.3%
	Nb	0.5	85	
25	Al	0.3	171	30.4%
	Nb	0.6	102	
30				

Thus, at ordinary operating situations, the 50 micron Nb filter results in 30 to 50% dose reductions to the patient.

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Although various preferred embodiments of the present invention have been described herein in detail, it will be appreciated by those skilled in the art, that variations may be made thereto without departing from the spirit of the invention or the scope of the appended claims.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An X-ray apparatus for medical or dental
diagnosis comprising an x-ray source operating at a peak
voltage of between about 55 keV and about 110 keV for
5 investigation of an examination object subjected to X-
ray beams from the source;

said apparatus including a filter significantly
reducing low energy radiation absorption by the
10 examination object without significantly affecting
desired high energy radiation from said source, said
filter being selected to have x-ray filtering
characteristics such that the intensity of x-rays having
an energy of 50 keV is reduced by about 8% to about 35%
15 of the normal radiation levels,

said filter comprising one or more materials
containing as a major component elements selected from
the group consisting of aluminum and elements having
20 atomic numbers between 26 and 50.

2. An X-ray apparatus as claimed in claim 1
wherein said filter comprises a metal foil being of a
single elemental material.

3. An X-ray apparatus as claimed in claim 2
wherein said elemental material is selected from the
group consisting of niobium, copper, silver, tin, iron,
nickel, zinc, zirconium, aluminum or molybdenum.

4. An X-ray apparatus as claimed in claim 1
wherein said filter comprises at least a niobium metal
foil having a maximum thickness of about 75 microns.

5. A filter for use with an X-ray apparatus for
medical or dental diagnosis wherein the X-ray apparatus

includes an x-ray source operating at a peak voltage of between about 55 keV and about 110 keV and an examination object subjected to X-ray beams from the source;

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said filter significantly reducing low energy radiation absorption by the examination object without significantly affecting desired high energy radiation from said source, said filter being selected to have x-ray filtering characteristics such that the intensity of x-rays having an energy of 50 keV is reduced by about 8% to about 35% of the unfiltered levels,

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said filter comprising at least one elemental material selected from the group consisting of niobium, copper, silver, tin, iron, nickel, zinc, zirconium, aluminum and molybdenum.

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6. A filter as claimed in claim 5 wherein said filter comprises a metal foil being of a single elemental material.

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7. A filter as claimed in claim 6 wherein said elemental material is selected from the group consisting of niobium, copper, silver, tin, iron, nickel, zinc, zirconium or molybdenum.

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8. A filter as claimed in claim 5 wherein said filter comprises at least a niobium metal foil having a maximum thickness of about 75 microns.

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9. A filter as claimed in claim 8 wherein said niobium metal foil has a preferred thickness within the range of about 25 to about 75 microns.

10. A filter as claimed in claim 9 wherein said niobium metal foil has a thickness of about 50 microns.

11. A filter as claimed in claim 8 including additional filtering foils in combination with said niobium metal foil with said filter maintaining a maximum thickness of about 75 microns.

12. A filter as claimed in claim 5 encased in a transparent cover.

13. A filter as claimed in claim 12 wherein said transparent cover comprises a flexible plastic.

14. A filter as claimed in claim 13 including a colour backdrop within said transparent cover, the colour in said backdrop identifying specific information regarding the filter.

15. A filter as claimed in claim 14 wherein said colour backdrop comprises a cardboard material and wherein said transparent cover comprises a flexible plastic resulting in overall flexibility of said filter.

16. A method for reducing radiation dose to an examination object being exposed to an X-ray beam during medical or dental diagnosis said method comprising

emitting a beam of penetrating radiation having a maximum energy of between about 55 keV and about 110 keV from an X-ray apparatus toward the examination object, said X-ray apparatus including an X-ray source operating at a peak voltage of between about 55 keV and about 110 keV and having inherent filtration equivalent to 2 to 4 mm of aluminum,

positioning a filter material between said X-ray source and said examination object, said filter significantly reducing low energy radiation absorption by the examination object without significantly affecting desired high energy radiation from said

source, said filter comprising one or more materials containing as a major component elements selected from the group consisting of aluminum and elements having atomic numbers between 26 and 50 and being selected to have x-ray filtering characteristics such that the intensity of the radiation having an energy of 50 keV is reduced by about 8% to about 35% of the normal radiation levels,

exposing said examination object to the filtered radiation such that most of said filtered radiation passes through said patient,

detecting the filtered radiation emerging from said examination object, and

processing the emerged filtered radiation to provide a radiographic image of the examination object corresponding to the intensity of the emerging filtered radiation.

17. A method as claimed in claim 16 wherein said filter comprises a metal foil being of a single elemental material.

18. A method as claimed in claim 17 wherein said elemental material is selected from the group consisting of niobium, copper, silver, tin, iron, nickel, zinc, zirconium, aluminum or molybdenum.

19. A method as claimed in claim 18 wherein said filter comprises at least a niobium metal foil having a maximum thickness of about 75 microns.

20. A method as claimed in claim 19 wherein said niobium metal foil has a preferred thickness within the range of about 25 to about 75 microns.

AMENDED CLAIMS

[received by the International Buresu on 26 June 1989 (26.06.89)
original claim 5 amended; other claims unchanged (2 pages)]

material being shown in brackets:

5. A filter for use with an x-ray apparatus for medical or dental diagnosis wherein the x-ray apparatus includes an x-ray source operating at a peak voltage of between about 55 keV and about 110 KeV and an examination object subjected to x-ray beams from the source;

said filter comprising at least one elemental material selected from the group consisting of niobium, copper, silver, tin, iron, nickel, zinc, zirconium, aluminum and molybdenum;

said filter significantly reducing low energy radiation adsorption by the examination object without significantly affecting desired high energy radiation from said source [said filter being selected to have x-ray filtering characteristics] and having a thickness range appropriate for the particular elemental material selected such that the intensity of x-rays having an energy of 50 keV is reduced by between about 8% [to] and about 35% of the unfiltered levels[.] .

[said filter comprising at least one elemental material selected from the group consisting of niobium, copper, silver, tin, iron, nickel, zinc, zirconium, aluminum and molybdenum.]

As shown above, the paragraph of Claim 5 providing that the filter comprise at least one elemental material selected from a certain group has been moved to follow the initial paragraph of the claim. Furthermore, the claim has been amended to specify that the filter have "a thickness range appropriate for the particular elemental material selected." Also, the description of the range of intensity reduction has been clarified. Claims 1-4 and 6-20 are unchanged.

includes an x-ray source operating at a peak voltage of between about 55 keV and about 110 KeV and an examination object subjected to x-ray beams from the source;

5 said filter comprising at least one elemental material selected from the group consisting of niobium, copper, silver, tin, iron, nickel, zinc, zirconium, aluminum and molybdenum.

10 said filter significantly reducing low energy radiation adsorption by the examination object without significantly affecting desired high energy radiation from said source and having a thickness range appropriate for the particular elemental material selected such that the intensity of x-rays having an energy of 50 keV is reduced by between about 8% and about 35% of the unfiltered levels.

15 6. A filter as claimed in Claim 5 wherein said filter comprises a metal foil being of a single elemental material.

20 7. A filter as claimed in Claim 6 wherein said elemental material is selected from the group consisting of niobium, copper, silver, tin, iron, nickel, zinc, zirconium or molybdenum.

8. A filter as claimed in Claim 5 wherein said filter comprises at least a niobium metal foil having a maximum thickness of about 75 microns.

25 9. A filter as claimed in Claim 8 wherein said niobium metal foil has a preferred thickness within the range of about 25 to about 75 microns.

10. A filter as claimed in Claim 9 wherein said niobium metal foil has a thickness of about 50 microns.

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FIG. 2.

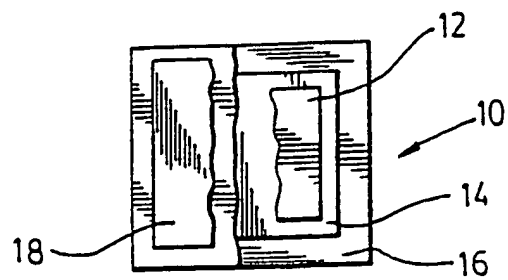
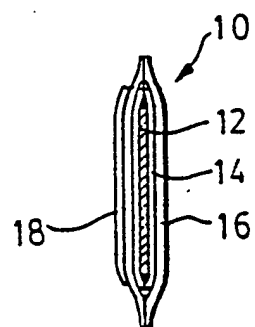
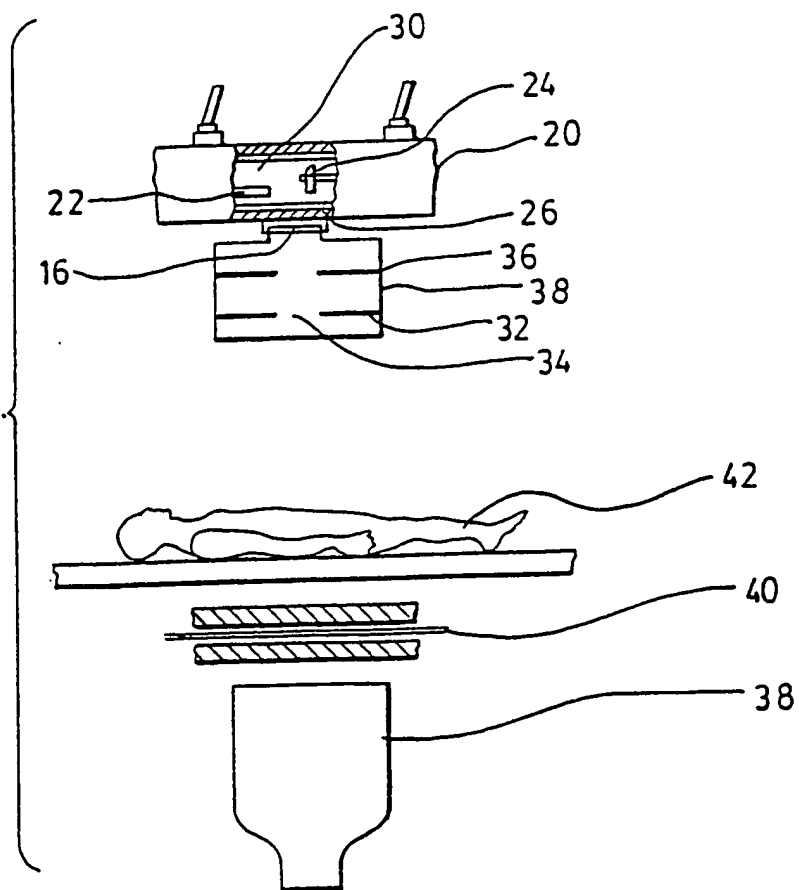


FIG. 1.

FIG. 3.



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FIG. 4.

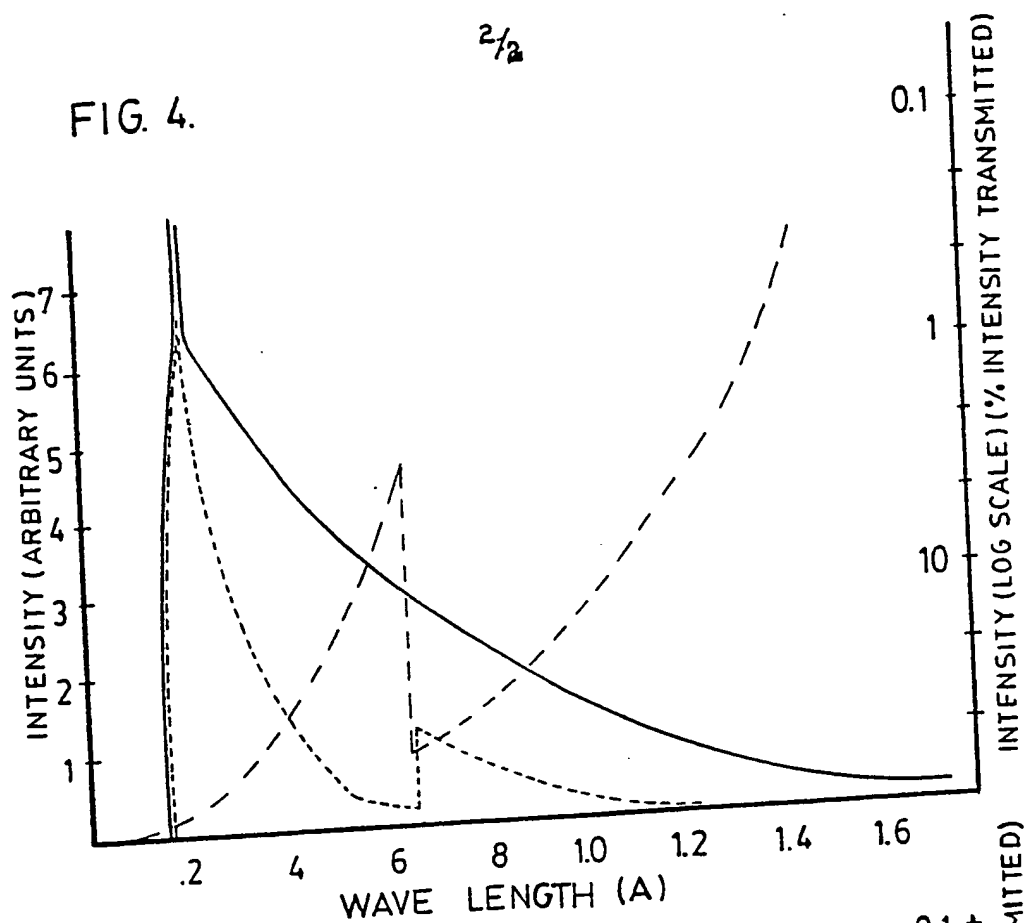
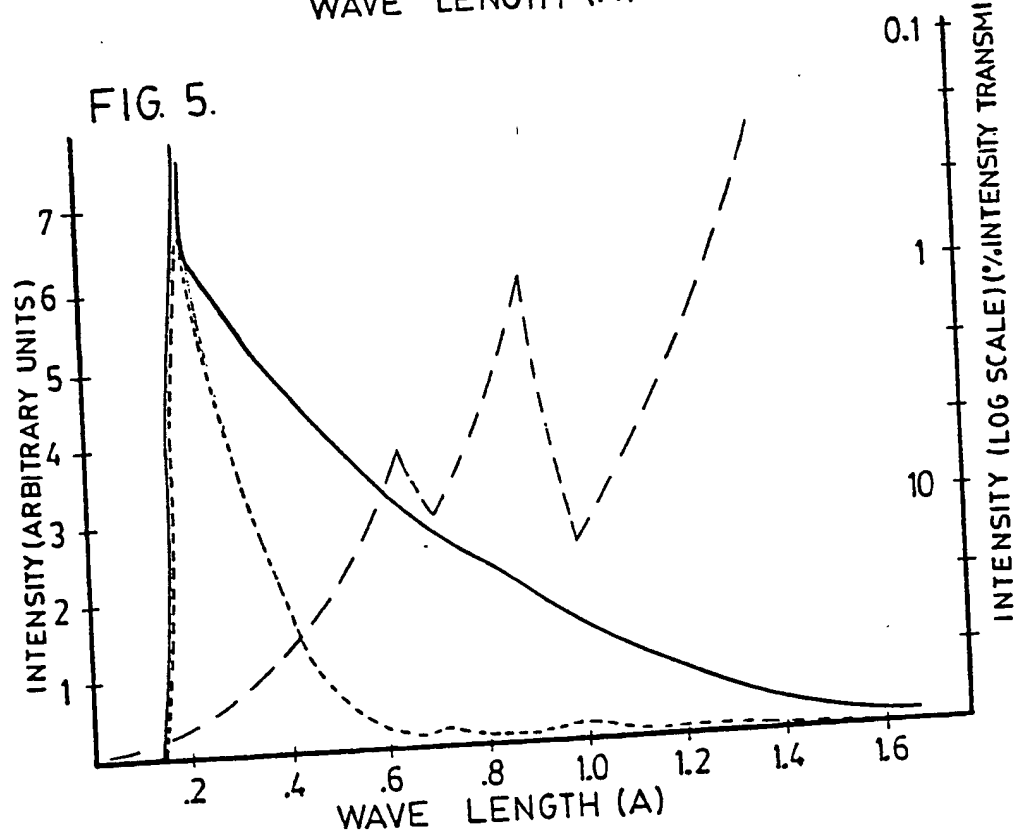



FIG. 5.



INTERNATIONAL SEARCH REPORT

- International Application No. PCT/US 89/00265

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC IPC(4): G21K 3/00 U.S. C1. 378/156		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
U.S.	378/156-158	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	US, A, 4,499,591 (Hartwell) 12 February 1985 See Entire Document	1-20
x y	DE, A, 2,211,090 (Zeller) 28 September 1972 See entire document	5 1-4, 6-20
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>¹⁰ Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p> </div> </div>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
15 March 1989		26 APR 1989
International Searching Authority		Signature of Authorized Officer
ISA/US		 Craig Church